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Ozone Measurement System for NASA Global Air Sampling Program

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SUMMARY

The ozone measurement system used in the NASA Global Air Sampling Program is described. The system uses a commercially available ozone concentration monitor that was modified and repackaged so as to operate unattended in an aircraft environment. The modifications required for aircraft use are described along with the calibration techniques, the measurement of ozone loss in the sample lines, and the operating procedures that were developed for use in the program.

The stability of the 10 flight instruments over 12 months (seven calibrations per instrument) is within 1 percent. The random error of the total system measurement was from 3 to 8 percent of reading (depending on the pump diaphragm material) or 3 parts per billion by volume, whichever was greater. Recent calibrations of the Lewis Research Center's ozone transfer standard indicate that GASP ozone data published to date are approximately 9 percent high.

INTRODUCTION

Global Air Sampling Program (GASP) systems are making daily measurements of ozone in the range 3 to 1000 parts per billion by volume (ppbv). The measurements are made in the upper troposphere and lower stratosphere (6 to 13 km) on flights of commercial airliners (refs. 1 and 2). GASP systems have been installed on a United Airlines B-747, a Qantas Airways B-747, two Pan American World Airways (Pan Am) B-747's, and the NASA CV-990 research aircraft. Initial ozone data were reported (ref. 3) from a March 1975 Pan Am flight. Since then GASP systems have flown for over 40 000 hours, with ozone data taken approximately 50 percent of the flight time for a total of 20 000 hours. These ozone data plus other trace constituents data are available from the National Climatic Center, Ashville, North Carolina. A series of reports by the Lewis Research Center (refs. 3 to 8) describe GASP flight routes, dates, data-processing procedures, and data-tape specifications. Selected analyses of ozone data are also included in the reports.

The instrument used for GASP ozone measurement is a commercially available instrument made by Dasibi Environmental Corp. that was specially modified by the manufacturer for Lewis. The required modifications included changes in the readout and controls to permit the instrument to work in the fully automated GASP system; changes in the packaging to meet airline standards; and other changes necessary to meet environmental requirements for shock, vibration, and electromagnetic interference. The

GASP system, including the ozone instrument, received a Federal Aviation Administration (FAA) supplemental certification to permit its use on B-747 aircraft in commercial service.

This paper describes the ozone measurement system in sufficient detail so that a potential user of the GASP ozone data can judge the quality of the data. Included are a description of the instrument, modifications made for aircraft use, integration of the instrument into the GASP system, calibration techniques, and measurements of ozone loss in the GASP sampling system that result in correction to the ozone data. An error analysis of the ozone measurement system is also included.

THE GASP SYSTEM

General Description

The GASP measurement system is an automated air-sampling system mounted on airline-operated B-747 aircraft. It measures selected constituents of the upper atmosphere between 6 and 13.7 kilometers altitude (refs. 1 and 2). The system has three functional elements: (1) the sample-collecting and handling system, (2) the measuring instruments, and (3) the data-acquisition and control system.

Sample-collecting and handling system. - Two air-sampling inlets in a single strut mounted outside the aircraft near the nose are used to sample gases and particulates. One inlet is designed for near-isokinetic sampling and is used for particle measurements. The air sample from the other inlet is pressurized with a diaphragm pump for some measurements, including ozone, to achieve the desired measurement sensitivity. A pressure regulator is set to control the inlet pressure to the instruments to 0.99±0.02 atmosphere; it then actually controls to within ±0.01 atmosphere of the set point at aircraft altitudes to 13.7 kilometers. Both inlets and the downstream vents are closed when the aircraft is below 6 kilometers to prevent contamination within the air-sampling system.

Measuring instruments. - The GASP-equipped aircraft contain instruments for measuring ozone, carbon monoxide, water vapor, particle number density, and condensation nuclei. A particulate-filter collector with several individual filter holders that can be sequentially exposed is also installed on two GASP B-747 aircraft.

Data-acquisition and control system. - A data management and control unit (DMCU) controls all data acquisition. The DMCU, which contains a special-purpose preprogrammed computer with 8K memory also provides certain data-acquisition functions. Additional data acquisition is handled by a standard, flight data-acquisition unit. All data are recorded on a flight digital cassette recorder. Aircraft system inputs recorded by the GASP system are position (latitude and longitude), heading, altitude, airspeed, vertical acceleration, computed wind velocity and direction, static air temperature, date, and time.

Automatic control of all system operations is also provided by the DMCU. The system is turned on during aircraft preflight operations. The computer operates in a standby condition until a signal is received from the altimeter to set up the system for sampling. A basic 60-minute sampling cycle is constructed by alternating 5-minute air-sampling periods and 5-minute instrument control periods. Thus, there are six sample readings and six instrument control mode outputs taken each cycle. All data are recorded during a 16-second interval at the end of each 5-minute air-sampling or control period. Instrument control modes are used for in-flight checks. Some instruments do not require all six control modes. Where control-mode data are not needed, air-sample readings are taken. As the aircraft descends through the 6-kilometer altitude level for landing, the system is returned to a standby condition. In the standby condition the two air-sampling inlets and the downstream vents are closed. More details on these parts of the GASP system are available in reference 1.

Ozone-Monitor Sample Flow System

The sample flow path for ozone measurement is shown in figure 1. Sample gas flows through the inlet scoop to the diaphragm pump and then to the instrument manifold. Manifold pressure is controlled with a backpressure regulator. In the normal air-sampling mode, the sample gas from the manifold flows directly to the ozone monitor. In the zero-gas instrument control mode the three-way valve is energized and directs the sample gas through the ozone scrubber and then to the ozone monitor. From the ozone monitor the gas flows through the orifice and venturi to the exhaust vent.

Ozone can be lost in the sample flow system and result in erroneous measurements. Ozone is lost by thermal decomposition due to the heat rise in the pump and by chemical reaction with various materials such as contaminants in the flow system. Also, numerous substances catalyze thermal decomposition. To minimize ozone destruction in the sample flow system, Teflon lines are used from the scoop to the instrument and the pump, excluding the diaphragm, is internally coated with Teflon. The rubber diaphragm is covered with a Teflon-impregnated fiberglass cloth material. When the aircraft is below 6 kilometers altitude, the scoop cover and the inlet and exhaust solenoid valves are closed to minimize contamination. System ozone loss is measured periodically, as described in the section Ozone-Destruction Measurement.

Pressurizing the sample gas to 1 atmosphere increases the sensitivity of the ozone measurement by increasing the number of ozone molecules per unit volume. Since the sample inlet pressure varies from 0.2 to 0.6 atmosphere, the sensitivity is increased by as much as a factor of 5. Pressurization also eliminates leaks from the cabin into the system and, because the manifold pressure is constant, the instrument sample flow rate is also constant.

The gas pressure, temperature, and flow rate through the instrument are measured. The sample gas pressure and temperature are measured at the manifold upstream of the instrument and are used for density corrections to the ozone readings. The pressure measurement is also used to monitor the condition of the pump and the pressure regulator.

The sample flow rate through the instrument is controlled by the orifice and venturi at the monitor outlet. The diameters of these elements were chosen so that, with proper sample flow rate, the orifice pressure drop holds the venturi inlet pressure to approximately 0.68 atmosphere, and the venturi is thus choked. A pressure transducer between the orifice and the venturi indicates proper sample flow rate.

THE OZONE MONITOR

Principle of Operation

The instrument used for GASP ozone measurement operates on the principle of absorption of ultraviolet (UV) light by ozone (ref. 9). No chemical reagents are required. The amount of light transmitted through the sample is expressed by the Beer-Lambert law

$$\frac{I}{I_0} = \exp\left(\frac{-273\ CPkL}{T\times 10^9}\right) \tag{1}$$

where

I/I_0 transmittance of sample

C ozone concentration, ppbv

P sample-gas pressure, atm

k ozone absorption coefficient at 253.7 nanometers, 273 K, and 1 atmosphere; 308.5 cm^{-1} atm^{-1} (base e)

L path length, cm

T sample-gas temperature, K

Construction

A block diagram of the ozone monitor is shown in figure 2. The monitor has three parts: the light source and detectors, the absorption chamber, and the electronics.

The light source is a low-pressure mercury lamp whose output is a series of emission lines at various wavelengths. Ninety percent of the light emitted is at 253.7 nanometers, which is very near the wavelength of maximum absorption of UV light by ozone. A Vycor filter on the lamp eliminates the 184.9- and 193.6-nanometer emission lines, which generate ozone. The UV light intensity is detected by two cesium-telluride photodiodes. The light intensity is measured directly by the control detector and, after it passes through the absorption chamber, by the sample detector. The output of the detectors is converted into pulses by the two digital electrometers. The number of output pulses per second is proportional to the detected light intensity.

The absorption chamber is a folded-tube arrangement with an effective length of 71 centimeters. The tubes are aluminum, internally coated with Kynar, and have quartz windows and mirrors. Depending on the position of the three-way solenoid valve, the sample gas flows either directly into the absorption tube or through the ozone scrubber and then into the absorption tube.

The electronics consist of two pulse counters capable of counting up and down, the output circuit (shift register), and logic circuits that control the instrument operation.

Operation

The instrument operates in a timed cycle of 20 seconds, as shown in figure 3. During the first 10 seconds of the cycle the three-way valve is activated and directs the sample gas through the ozone scrubber, which destroys all ozone and generates a zero gas. After a 5-second flush of zero-gas flow to the absorption chamber, the sample and control counters start counting the pulses generated by the two electrometers. During this part of the cycle the sample counter counts up to a preset number, called the span, and then stops the control counter. After 10 seconds the three-way valve is deactivated and the gas sample flows directly into the absorption chamber. After a 5-second flush in this sample mode, the two counters count down. The control counter counts down to zero and stops the sample counter. If there is any ozone in the gas sample, it will absorb UV light during the downcount and thus decrease the pulse rate output from the sample electrometer and leave a residual count in the sample counter. If the proper preset number (the span) is chosen, the residual output count will numerically equal the ozone concentration in ppbv. This combination of the sample and control circuits (detectors, electrometers, and counters) compensates for changes in the source UV intensity and in the transmittance of the optical components.

The output of the ozone monitor is a 24-bit digital word. This word is made up of six binary-coded decimal digits. The five least signficant digits indicate the ozone output when the instrument is in an air-sampling mode. The most significant digit indicates in which mode (air sampling or control) the instrument is operating when the measurement is made.

The ozone monitor uses four of six instrument control-mode periods for in-flight checks. This leaves two of the control periods for additional ozone measurements. Thus a total of eight ozone measurements are made per hour.

The in-flight checks are used to monitor the instrument zero and span and the sample and control pulse rates. In control mode 1 the three-way valve shown in figure 1 is activated and directs the sample gas through the ozone scrubber and then into the instrument. The scrubber destroys all the ozone and the instrument reads out the zero-gas output. Monitoring the zero-gas output with time gives an indication of instrument stability.

In control mode 2 the sample counter is used to read out the preset span. The output of the instrument is a function of the span, which is a 5-digit number. In this mode the instrument should read out the exact value of the span for correct operation.

In control modes 3 and 4 the sample counter is used as a 1-second counter, and the instrument can read out the sample or control pulse rate. For proper operation of the instrument, the sample pulse rate is maintained between 250 and 480 kilohertz. The control pulse rate is maintained above 200 kilohertz but less than the sample pulse rate. Deviations from the originally adjusted sample and control pulse rates can indicate a shift in the position of the detectors or a change in the intensity of the UV source. Deviation in the sample pulse rate can also indicate contaminants in the absorption tube or on the windows.

Instrument Modifications for GASP Use

The instruments were modified to meet the safety requirements of the airlines and the FAA, to meet accepted commercial-aircraft standards, to operate in the aircraft environment, and to operate in the fully automated GASP system.

One of the safety requirements was a modification to reduce to Boeing Co. standards the electromagnetic interference (EMI) generated by the instrument. To reduce EMI, the instruments were mounted in shielded enclosures and EMI filters were installed on all input and output lines to the instrument. Electronic circuits were also modified to eliminate sharp electrical spikes and unwanted oscillations.

Modifying the instruments for shock and vibration involved a combination of safety, environmental, and commercial-standards requirements. The instruments were repackaged and constructed on reinforced Aeronautical Radio Incorporated (ARINC) chassis that were mounted on ARINC trays. The trays, chassis, components, and mounting of components in the chassis had to meet the shock and vibration requirements of RTCA Document Number DO-138 (ref. 10). These requirements include operation of the instrument to specification after standard vibration tests and operational shocks. No structural failure should occur after shock tests that simulate a crash condition.

To meet other environmental requirements, the instruments had to operate over the temperature range -10° to 40° C and the pressure range 0.6 to 1.0 atmosphere. The instrument also had to operate from the aircraft 400-hertz supply. This required protecting the aircraft supply from instrument faults with a circuit breaker and an overtemperature thermostat.

So they could operate in the fully automated GASP system, the following modifications were made to the ozone monitors:

(1) The manual control-mode switch that selects the output mode (normal, span, sample pulse rate, or control pulse rate) was replaced with logic circuits activated by contact closures controlled by the DMCU.

(2) The visual data display was replaced with an output shift register that is clocked out with pulses generated by the DMCU.

(3) A circuit was added to generate a unique identification voltage for each instrument.

(4) Some of the instruments have negative offsets for zero-gas input, but the original counting logic prohibited reading out negative numbers. Since the cause of the offset was not determined, the counting logic was modified to read out the negative offset.

Testing and FAA Certification

A test program was developed in order to obtain FAA certification of the monitor for operation on a B-747 aircraft flying in commercial service. This test program was based on the philosophy that the monitor should not interfere with the operation of the aircraft or create a hazardous condition while it is operating on the aircraft. Primary emphasis was placed on electromagnetic interference compatibility testing and on determining if any problems resulted when the monitor was operated on an aircraft power system. Also included in the program were shock and vibration tests.

Electromagnetic interference testing was based on the procedures given in Boeing Co. standards for aircraft systems. Tests were made for both interference generation and susceptibility effect.

Similarly, tests were made to determine if any problems resulted from operating with various steady-state alternating-current voltage and frequency combinations that might be encountered on B-747 aircraft. Also, operating tests were performed under both normal and abnormal transient power conditions. The test procedures were based on Boeing Co. standards.

Shock and vibration tests were performed according to procedures described in reference 10. Some additional vibration tests were performed by NASA to ensure that components were securely fastened and to determine that no chafing problems existed in the internal wiring. Experience has shown that shocks encountered in normal handling and shipping are much more severe than those specified in the test procedure even though the monitors are shipped in padded containers.

A reliability and quality assurance test program was also developed for the monitor. The purpose of the reliability tests was to eliminate early component failures and basic flaws in the design and construction of the instruments and to increase overall instrument reliability. This program involved a burn-in test, requiring 168 hours of operation at room temperature, and thermal cycling tests. The thermal cycling tests consisted of cyling the monitor 20 times between 60° and -40° C.

OPERATIONAL CONSIDERATIONS

Ozone-Destruction Measurement

In the GASP system, some ozone is destroyed upstream of the ozone monitor. Most of the ozone destruction is caused by the temperature rise of the sample gas in the pump. A second cause of ozone destruction is contamination in the sample flow line and in the pump. The amount of destruction varies with different pumps and with time in the same pump. Pumps are tested to determine the amount of ozone destruction before they are installed on a GASP system. Pumps that exhibit excessive destruction are recleaned and retested before installation. Normally, the amount of destruction in a system decreases with time but will increase if the system is contaminated from failure of a component, such as the pump diaphragm. An ozone-destruction test package was developed at Lewis to determine the amount of ozone destruction in a GASP system after the pump is installed in an aircraft.

Figure 4 shows the ozone-destruction test package connected to an ozone monitor in a GASP system. The ozone generator is an ultraviolet lamp capable of generating ozone concentrations from zero to 1500 ppbv at airflows to 30 liters per minute. The concentration is controlled by varying the lamp intensity. GASP inlet pressures (0.2 to 0.6 atm) are generated with the combination of the flow restrictor and GASP-system pump and are measured with pressure gage P1. Pressure gage P2 measures the inlet pressure to the ozone monitor. This measurement is used for density corrections to the ozone-monitor output readings.

Air enters the combination drier and charcoal filter and then flows through the particle filter to the test-package pump. From this pump the air goes into the ozone generator, through the flow restrictor, and into the GASP system downstream of the inlet. If the three-way valve is activated, some of the flow bypasses the system pump and manifold and goes directly to the ozone monitor. Excess air from the ozone generator flows through the charcoal scrubber to the atmosphere.

With this test package the ozone concentration of a test sample is measured before it enters the GASP system and is compared with the ozone concentration as normally measured by the GASP system. This is done by the same instrument so that variations in instrument calibration are not a source of error. This approach requires short-time stability of ozone concentration, which can be easily verified, and assumes that the ozone concentration does not change as the sample expands through the flow restrictor.

At any one ozone concentration a series of data points are taken and then averaged. Comparisons between readings are made at concentrations from zero to 1000 ppbv. Figure 5 shows a typical ozone destruction curve. The curve is linear and the amount of destruction is 13 percent. The initial test data from different systems and pumps indicate an average destruction of 16 percent, with a random error in determining the amount of destruction as high as ±8 percent. The amount of destruction was reduced to less than 6 percent when the Buna-N rubber diaphragms were changed to silicone rubber. The random error was also reduced to ±2 percent. The ozone destruction tests are made periodically and the data are used to correct GASP-system ozone data.

Calibration and Error Analysis

All ozone monitors are calibrated with a secondary transfer standard before installation into GASP systems. This transfer standard is a Dasibi model 1003-AH that was initially calibrated by using a 1-percent-neutral-buffered-potassium-iodide method (ref. 11). Later in the GASP program the transfer standard was calibrated at the Jet Propulsion Laboratory (JPL). This calibration is traceable to JPL's 5-meter photometer described in reference 12.

Figure 6 shows the test setup used to compare the GASP ozone monitors against the secondary standard. Clean, dry air is used as a source for the ozone generator and as a zero gas. A charcoal filter is also used to ensure that there are no interfering gases or any contaminants from the pressure regulator. The air enters through a pressure regulator and a charcoal filter into an ozone generator or through the needle valve to the four-way valve. The four-way valve allows sample gas from the ozone generator or zero gas to pass through the test instrument and the transfer standard.

Since the instruments are linear over the range of interest, a two-point comparison (zero gas and 1000 ppbv) is used. Twenty-five readings are taken at zero-gas concentration, and 25 readings are taken at 1000-ppbv concentration. Mean values and standard deviations are calculated for zero-gas output and 1000-ppbv output. The standard deviations are an estimate of the random error of a single reading. The standard deviations are less than 1 percent for 1000-ppbv output and less than 3 ppbv for zero-gas output.

The net output is determined by subtracting the mean value for zero gas from the mean value for 1000 ppbv. The normalized net output is obtained by dividing the net output of the test instrument by the net output of the transfer standard. Figure 7 summarizes the results in the form of normalized net output from 10 ozone monitors made over 1 year. A best straight-line fit of these data has a slope of less than 0.2 percent per year. The mean value of the normalized net outputs from all the monitors calibrated over the year is 1.005, which is a deviation of only 0.5 percent from an ideal value of 1.000. The plotted data show the stability with time of the 10 instruments compared with the transfer standard. The standard deviation from the mean of the normalized net outputs of all the monitors over the year's span is less than 1 percent. Because of the good agreement between the 10 monitors and the transfer standard, the calibration curve determined for the transfer standard is used for all GASP ozone monitors.

The Lewis secondary transfer standard is the same basic type of instrument as the GASP ozone monitors. The corrected concentration of ozone, in ppbv, for the secondary standard and GASP flight instruments is given by the following equation (ref. 13):

$$C(\text{ppbv}) = AR\left(\frac{T}{T_r}\right)\left(\frac{P_r}{P}\right) \tag{2}$$

where

A constant, function of instrument span and reference pressure and temperature

R instrument net output

T sample-gas temperature, K

T_r reference temperature, K

P_r reference pressure, atm

P sample-gas pressure, atm

The ozone secondary transfer standard was calibrated at Lewis initially with the 1-percent-neutral-buffered-potassium-iodide (KI) method. From this KI calibration the instrument span was adjusted so that A was 1 when the reference pressure and temperature were 1 atmosphere and 298 K, respectively. All data taken to date from the GASP ozone monitors have been corrected with the following equation:

$$C(\text{GASP}) = R\left(\frac{1}{298}\right)\left(\frac{T_m}{P_m}\right) \tag{3}$$

where T_m and P_m are the temperature and pressure of the sample gas in the instrument manifold upstream of the ozone monitor.

The accuracy and reproducibility of the KI method have been questioned by various researchers (refs. 12 to 15), and there are recommendations that the KI method be replaced with a UV photometry standard. So later in the program the GASP transfer standard was calibrated at JPL. From the average of three calibrations at JPL the constant A was found to be 0.92. If it is assumed that the UV photometer standard is correct, the ratio of the published GASP data to the true ozone concentration is 1.09. Thus all GASP data published to date are 9 percent high according to the JPL calibrations. This is a systematic error and can be easily corrected.

In addition to the systematic error the total random error of any reading is a combination of the following errors:

(1) The error in the JPL calibration of the GASP transfer standard, E_s, which is ±2 percent (private communication from Morris Patapoff, JPL, Pasadena, Cal.)

(2) The error in the calibration of each GASP instrument with the GASP transfer standard, E_g, which is ±1 percent (fig. 7)

(3) The error in measuring the sample-gas temperature-pressure ratio, $E_{t/p}$, which is estimated to be ±1 percent

(4) The error in determining the ozone destruction constant, E_d, which is estimated to be ±2 percent (when the pump diaphragm is silicone rubber) and ±8 percent (when the pump diaphragm is Buna-N rubber)

(5) The random error of a single ozone instrument reading, E_r, which is ±1 percent of the reading or 3 ppbv, whichever is greater, and is based on the standard deviation of repeated calibration points.

The total random error is the root-sum square of all the random errors:

$$E_{total} = \sqrt{E_s^2 + E_g^2 + E_{t/p}^2 + E_d^2 + E_r^2} \tag{4}$$

$$E_{total} = \sqrt{11} = \pm 3.3 \text{ percent of reading} \qquad \text{(silicone rubber)} \tag{5}$$

$$E_{total} = \sqrt{71} = \pm 8.4 \text{ percent of reading} \qquad \text{(Buna-N rubber)} \tag{6}$$

This error applies for output readings of 300 to 1200 ppbv. Below 300 ppbv the random error for a single reading E_r is ± 3 ppbv. The total random error is shown in figure 8. It approaches 3 ppbv at very low ozone concentrations.

Operating Procedures

Operating procedures were devised to ensure the intensity of the GASP ozone measurements. These procedures include in-flight checks of the instruments, ground checks of instruments on the aircraft, removal of instruments from aircraft for laboratory calibrations and maintenance if required, and maintaining logs on individual instruments.

In-flight checks are used to monitor the instrument zero and span and the sample and control pulse rates. The recorded outputs from the in-flight checks must be within specified limits or they are flagged by the data-processing computer. Instruments with flagged outputs may not be operating correctly or accurately and are replaced with spares. However, replacement of an instrument can generally be delayed by 4 weeks. This time may include 2 weeks of operation before a data tape is removed from the aircraft, 1 week for computer processing of the tape, and another week before the aircraft is accessible for removing the instrument. For this reason, ground checks are also made on instruments whenever an aircraft is accessible. Output readings identical to the in-flight readings are made. Sample frame readings are also made. The sample frame consists of data taken in flight and stored in the DMCU. It includes the last ozone data point and the outputs from the last control mode 1 and the last control mode 2. Readings are made visually with ground checkout equipment, and evaluations are made immediately to determine if the instrument should be replaced with a spare.

An instrument removed from an aircraft is calibrated first to check the validity of previously taken flight data. If adjustments or repairs are required, they are made after this initial calibration and then the instrument is recalibrated before it is reinstalled on an aircraft.

An equipment log is kept on all ozone monitors. The results of all calibrations, repairs, adjustments, and routine functional tests are recorded in the log on a data sheet (fig. 9) designed for the ozone monitor. The data sheet includes serial number, date of test or calibration, and a test number. Test numbers are used to document the order of tests and calibrations for any one period in the calibration laboratory.

The information on the ozone-monitor data sheet is used for various purposes. The calibration data of an instrument are used to check the validity of previous GASP data taken with that instrument. The statistical combination of all calibration data (fig. 9) is used to determine the stability of the measurement. The data sheet also is a check sheet to ensure that the instrument is functioning properly before it is returned to the field. The history of repairs has shown weak points in instrument design, and this has led to fixes that improve reliability. This history of repairs has also shown that most component failures were easy to detect from the instrument output data or ground checks. This type of failure caused loss of data, but there was no question when the data were bad. One type of failure was detected only with a laboratory calibration. This failure was caused by deterioration of the ozone scrubber. After 4 months of flight time, some of the scrubbers were less than 100 percent effective in destroying ozone. This caused the instruments to read as much as 30 percent low. This problem was eliminated by replacing the scrubbers after 3 months use.

SUMMARY OF RESULTS

Modified, commercial ozone monitors are used to measure ozone in the Global Air Sampling Program. These ozone measurements are made in the upper troposphere and lower stratosphere from commercial-airline flights of B-747 aircraft.

Operating procedures were set up to ensure the intensity of the data. These include instrument calibration techniques, measurement of ozone loss in the GASP sample lines, and periodic instrument maintenance.

The stability of 10 flight instruments (range, 3 to 1000 ppbv) over 12 months (seven calibrations per instrument) is within 1 percent. The random error of the total system measurement is from 3 to 8 percent of reading (depending on the pump diaphragm material) or 3 ppbv, whichever is greater. Recent calibrations of the Lewis ozone transfer standard indicate that GASP ozone data published to date are approximately 9 percent high.

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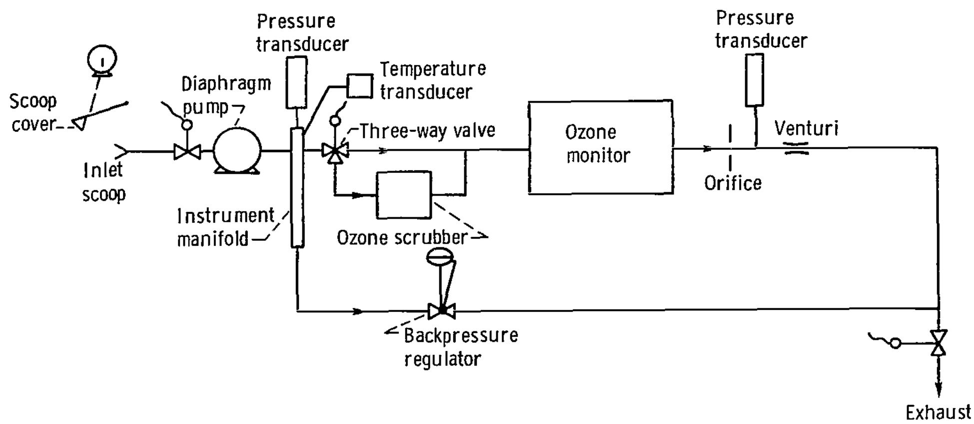

Figure 1. - Ozone-monitor sample flow system.

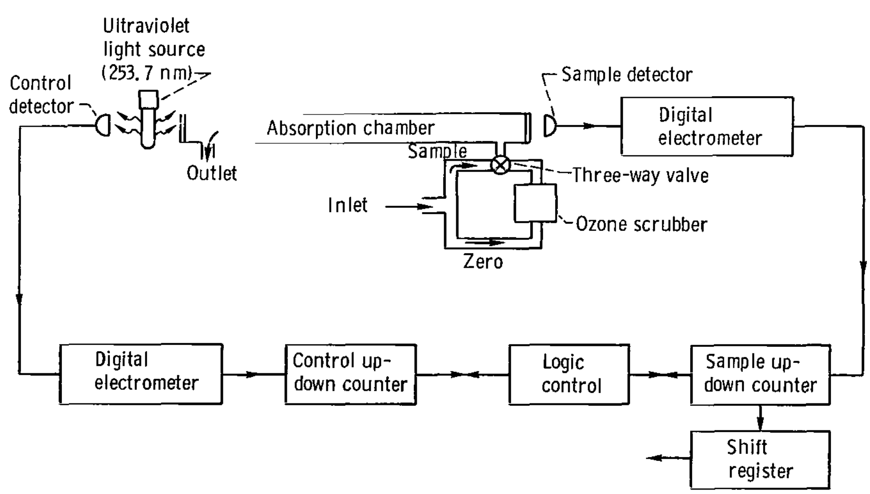

Figure 2. - Ozone-monitor block diagram.

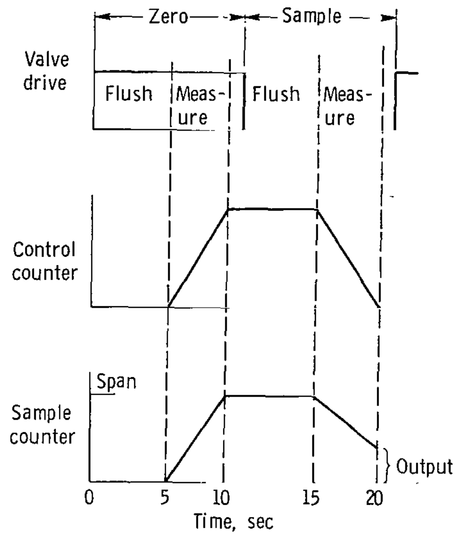

Figure 3. - Ozone-monitor timing cycle.

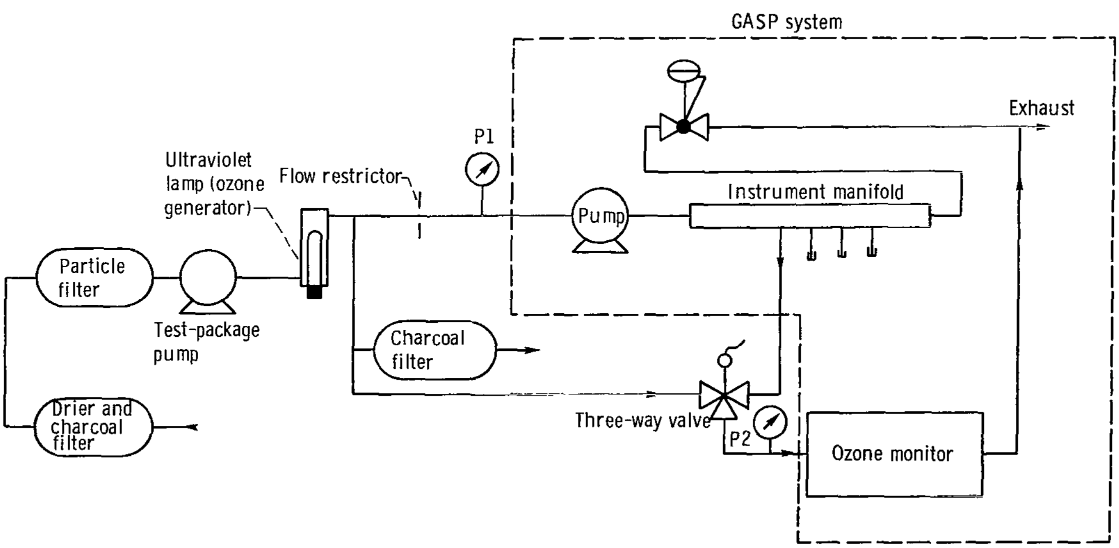

Figure 4. - Ozone-destruction-test setup.

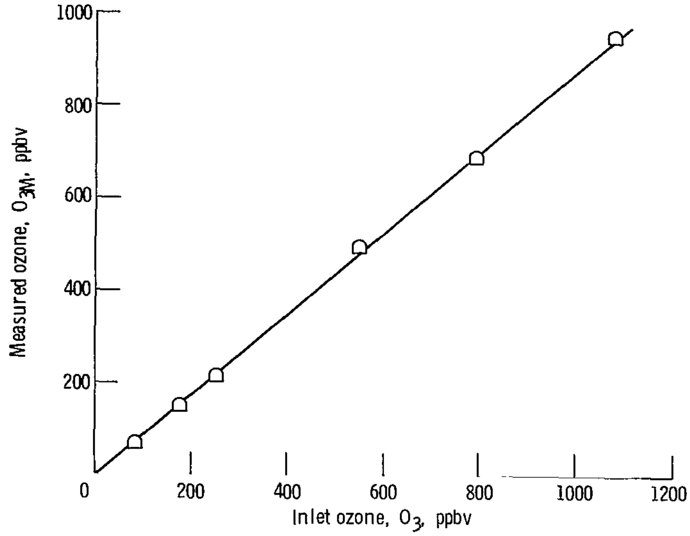

Figure 5. - Results from typical ozone-destruction test. Measured ozone equals 0.87 inlet ozone.

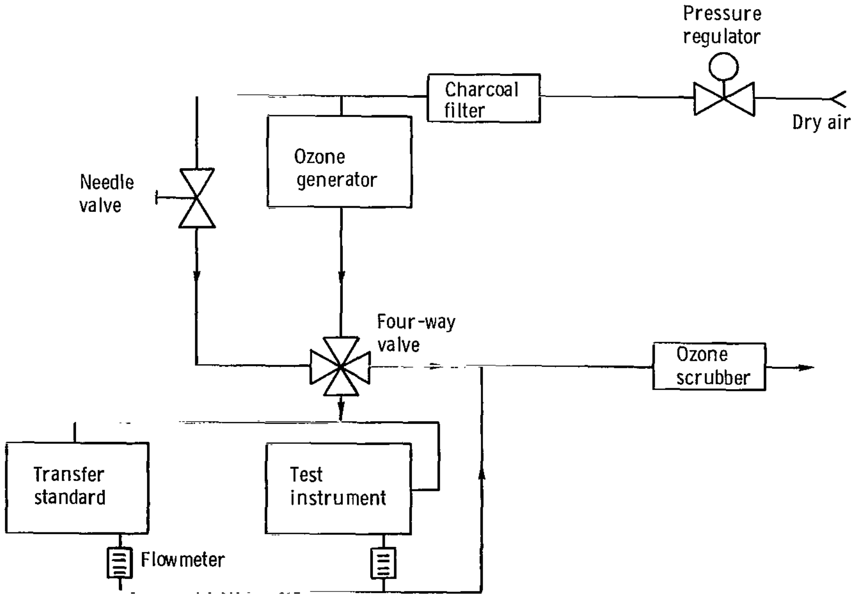

Figure 6. - Ozone calibration stand.

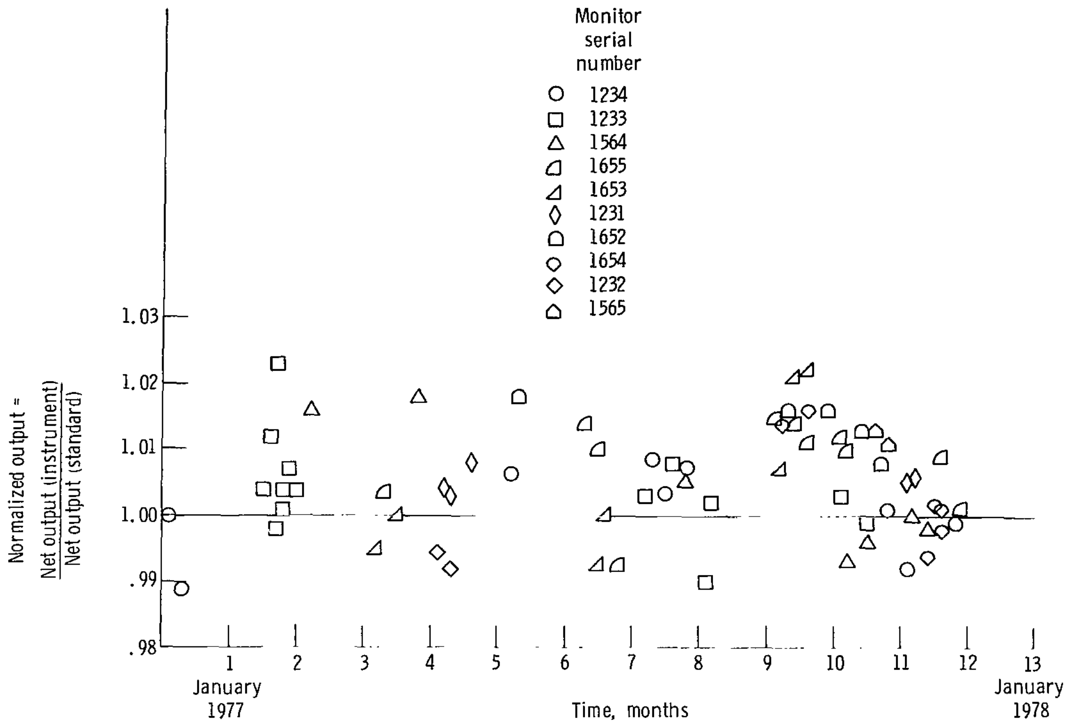

Figure 7. - GASP ozone monitor calibrations. Mean, 1.005; standard deviation, 0.8 percent.

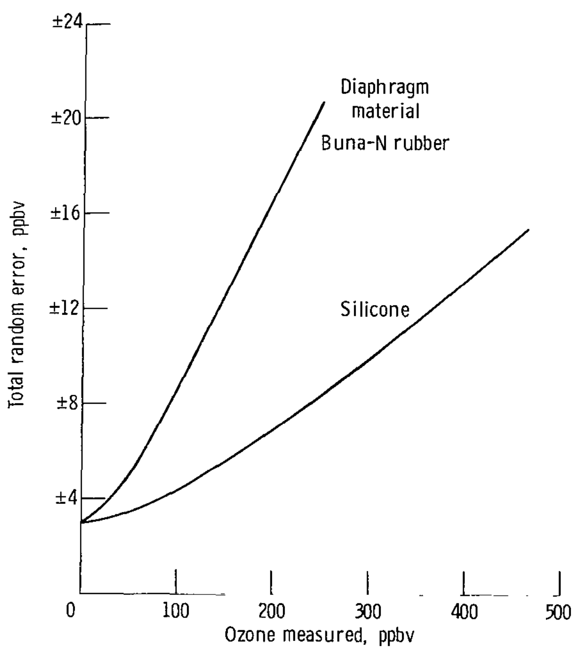

Figure 8. - Total random measurement error.

S/N 1231 DATE 7-24-78 TEST NO. 1

FUNCTIONAL TESTS

I.D. 010 INSTR. TEMP 110 OHMS (90-110)

Supply Voltages +15* 15.01 (±0.5), -15* -15.12 (±0.5),

5 4.96 (±0.3), 24 23.5 (±0.5).

* +12 and -12 volts for S/N 1652-1655

U.V. Block Temp 115 °F (115-122), Span 258200 (258200)

Sample Freq. 34636 (32000-46000)

Control Freq. 22696 (22000-27000)

Leak Rate .1 PSI/5 min (.5psi/5 min)

CALIBRATIONS

		Output with Zero Gas in MEAN	S.D.	Output with 1 ppm Input MEAN	S.D.	Δ Output (1 ppm-zero)	Δ Instr / Δ STD	Number of Reads
	STD	-7.6	1.0	1216.3	5.6	1223.9	.985	25
1	INSTR.	-16.6	1.4	1188.6	6.5	1205.2		25
2	STD	-8.4	1.0	1200.5	5.0	1208.9	.987	25
	INSTR.	-17.2	1.3	1176.2	5.6	1193.4		25

Reason Instrument Returned from Field:
CALIBRATION

Repairs or Adjustments made Before Function Tests or Calibration:
NONE

Figure 9. - Dasibi ozone-monitor data sheet.

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16. Abstract

The ozone measurement system used in the NASA Global Air Sampling Program is described. The system uses a commercially available ozone concentration monitor that was modified and repackaged so as to operate unattended in an aircraft environment. The modifications required for aircraft use are described along with the calibration techniques, the measurement of ozone loss in the sample lines, and the operating procedures that were developed for use in the program. Based on calibrations with JPL's 5-meter ultraviolet photometer, all previously published GASP ozone data are biased high by 9 percent. A system error analysis showed that the total system measurement random error is from 3 to 8 percent of reading (depending on the pump diaphragm material) or 3 ppbv, whichever are greater.

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